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PHENOMENOLOGICAL STUDY OF RADIATION DAMAGE AND RECOVERY OF METAL-OXIDE FIELD EFFECT TRANSISTORS

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PHENOMENOLOGICAL STUDY OF RADIATION DAMAGE AND RECOVERY OF METAL-OXIDE FIELD EFFECT TRANSISTORS

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SUMMARY

Exploration of space by scientific satellites has reached a stage where more precise and detailed observations and even partial data reduction capabilities have become a prime requirement. To achieve these goals, especially in small scientific satellites, the electronic design of a spacecraft circuitry has increased in complexity. However, the size, weight, and power available on spacecraft have not increased in proportion to the growth of observation capability and information processing complexity. In view of this it has become essential to optimize the weight, size, and power requirements of the electronic hardware. Although significant reduction in size and weight is being achieved by the application of conventional integrated circuit technology, insulated-gate field-effect devices offer the added advantage of a significant reduction in power without loss in the speed of operation. The simplicity of manufacturing insulated-gate field-effect transistors is also well suited to integrated circuit technology. This device offers great promise for application in space electronics except for one major limitation. The electrical characteristics of the available MOS devices degrade in a radiation environment.

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This paper gives a preliminary report of a study investigating radiation damage and the modes of the recovery process. This phenomenological study of recovery appears to reveal a possible model of damage mechanism.

The present investigation was carried out with very limited number of samples made by different manufacturers. Only P-channel enhancement mode devices were investigated and the source of radiation was a 1.5 Mev electron beam. The following type of devices made by the respective manufacturers were studied:

Type	Manufacturer
SC1128	General Micro Electronics
MEM 511	General Instrument
MM 2103	Motorola

The SC1128 is of monolithic construction and consists of three MOSFETs connected in series. Two of the three sections were shorted to substrate and only one MOSFET of the three was monitored. Figure 1 shows the circuit configuration in which the device was irradiated.

Ten samples of SC1128 were damaged with irradiation and their electrical characteristics were recovered by thermal annealing through four cycles. The parameter monitored was the gate voltage (V_{GT}) necessary to establish 10 ua current between drain and source (I_{DS}). Figure 2 gives typical response of a single device over repeated irradiation and recovery. The plot is of gate voltage necessary to obtain a 10 ua I_{DS} against the total dose of radiation. The four curves are

from four successive irradiation and thermal annealing cycles of one typical device. The thermal annealing was carried out by intermittently storing the devices at 200°C for a total time of sixteen to twenty hours. This consisted of heating the devices in an oven for a period of six hours continuously then leaving them in the oven overnight to cool to room temperature. During the period of heating and cooling the devices were kept in a passive state, i.e., no voltages were applied and with all leads shorted. All of the devices after similar treatment show nearly the same behaviour. One interesting feature revealed by the plot is the significant change in the rate of degradation on successive exposure to the same total dose of irradiation. This is indicative of some degree of radiation hardening achieved from this method of thermal treatment. A discussion of a possible mode of damage and evaluation of these results with observations on other devices is contained in a later section. Further investigation on the behaviour of these devices at higher total dose as well as higher thermal elevation should prove very interesting. Since these units were selected to be part of some flight hardware further work was terminated.

A similar number of MEM511 type devices manufactured by General Instrument were also studied. The annealing process adopted for these devices was slightly different from the one used for the SC1128s. These devices were annealed in an active state in contrast to the previous passive state, where no voltages were applied to the device electrodes. The devices

were heated to a temperature (280°C) such that even at zero gate voltage the unit was saturated and I_{DS} was limited with external resistance to 100 ua. Figure 3 shows the transfer characteristic of a sample unit after irradiation and after annealing showing a plot of drain-source current as a function of gate voltage.

This method of recovery to the nearly original gate threshold voltage is achieved within a very few minutes (about five). This quick recovery could be caused by interaction of current in the bulk material with trapped ions at the interface of the Si-SiO_2, assuming that most of the ions generated by ionization migrate and are trapped at this interface. The rate of degradation of these devices to successive irradiation after this method of recovery was not consistent among all the samples unlike the SC1128s. However, some of the samples did show a degree of radiation hardening. All the devices did recover to the original gate threshold or even lower values in this mode of recovery and in some of the samples there is a change in the transfer characteristic curve (I_{DS} vs. V_{GS}) after annealing.

The third type of device which was studied were P-channel enhancement type MM2103 made by Motorola. Figure 4 gives a plot of transfer characteristic of one of these samples after irradiation, as well as, after recovery. These devices were also recovered in the active state and all of the samples of this type showed much closer recovery to the original transfer

characteristic after the quick recovery process.

A sample of "N" channel enhancement mode device made by Motorola (Type MM2102) was irradiated and was found to go into the depletion mode. Since this was only one sample available for irradiation no further investigation could be carried out.

Most of the observations in this study of degradation and recovery could be explained on the basis that ions are trapped in the surface states at the interface of Si and SiO_2. These ions are generated by the radiation in the SiO_2, migrate and become trapped in these surface states. These ions are relatively immobile and counteract the field applied at the gate electrode which is attempting to form the channel. In the first mode of recovery of prolonged heating and cooling, the trapped ions are excited and allowed to recombine with carriers in the Si semiconductor region. In addition to the removal of these trapped ions, thermal annealing, i.e., removal of strain at the interface, also appears to occur. These heating and cooling cycles leave fewer surface states making the device less radiation sensitive. In the quick recovery mode one has the interaction of carriers of the bulk material with the trapped ion by recombining at the interface. In this mode of recovery where heat is applied for few minutes only, one does not achieve significant annealing, i.e., decrease in strain at the interface of Si-SiO_2. The device does recover to the original characteristic but it is not significantly radiation hardened. It is planned to study effect of doping SiO_2 with impurity to enable some of the generated ions to recombine with the free carriers available.

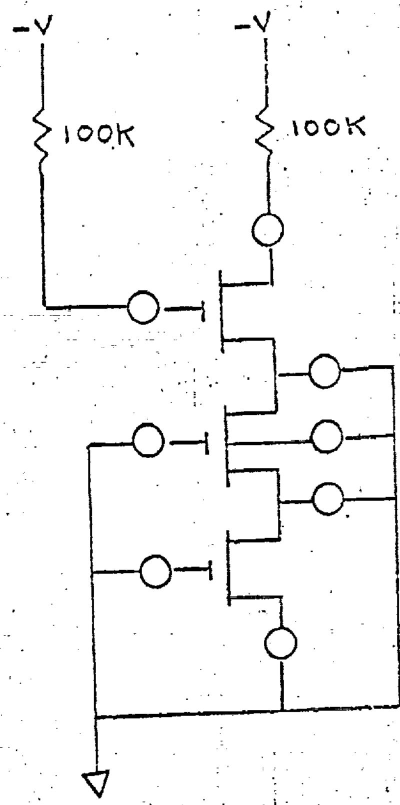
List of Captions

Figure 1 - Circuit configuration of SCL120 triple and gate as connected during radiation exposure.

Figure 2 - Plot of V_{GT} as a function of dose for a single SCL120 our four consecutive damage and recovery cycles.

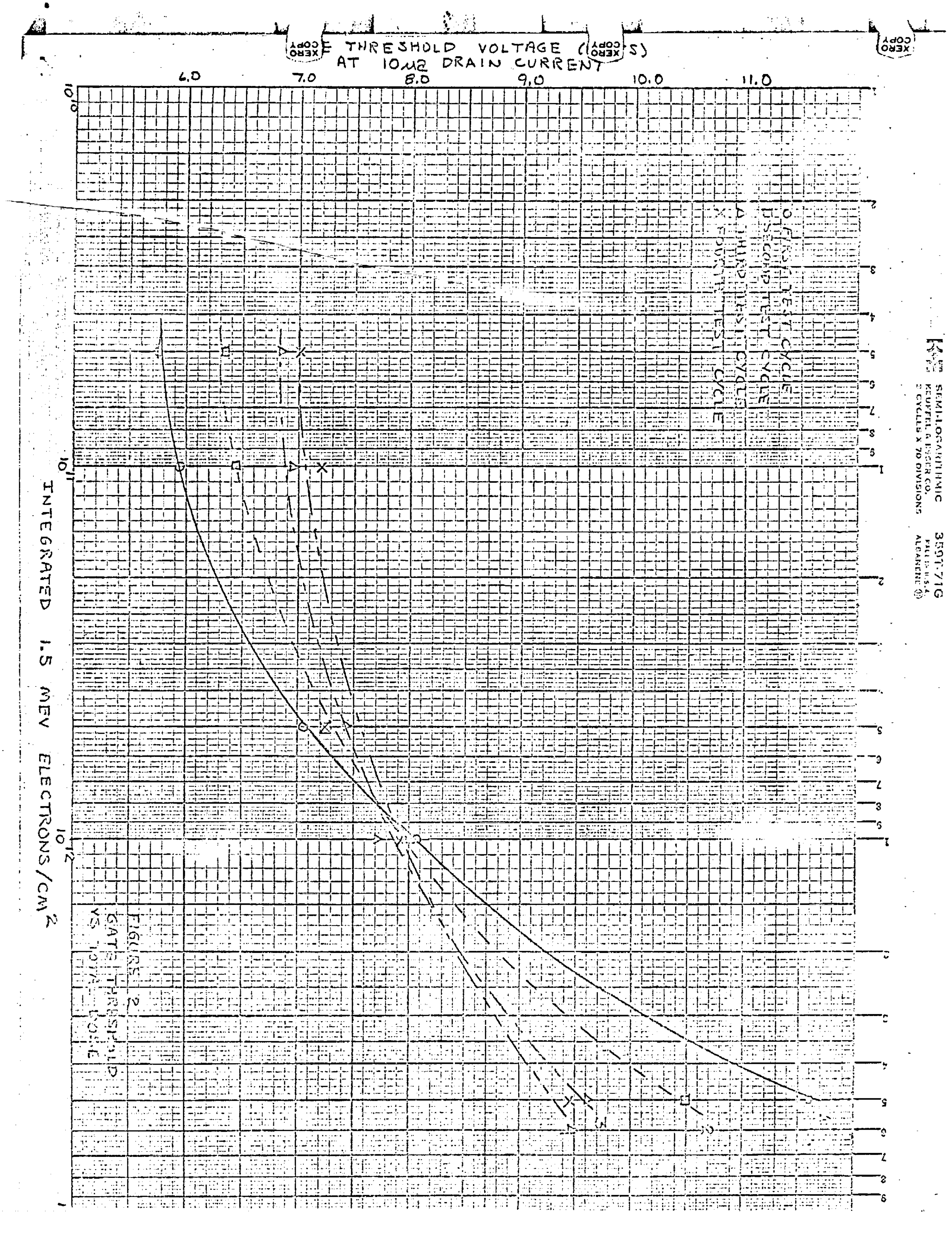
Figure 3 - Plot of I_{DS} as a function of V_{GS} after irradiation and after annealing for type MEM511.

Figure 4 - Plot of I_{DS} as a function of V_{GS} after irradiation and after annealing for type MM2103.



SC1128 CONFIGURATION
DURING EXPOSURE

FIGURE 1



THRESHOLD VOLTAGE
AT 10μA DRAIN CURRENT
6.0
7.0
8.0
9.0
10.0
11.0
O FIRST TEST CYCLE
□ SECOND TEST CYCLE
△ THIRD TEST CYCLE
X FOURTH TEST CYCLE
INTEGRATED 1.5 MEV ELECTRONS/CM²
FIGURE 2
GATE THRESHOLD
XERO COPY
SEMI-LOGARITHMIC
359T-71G
KEUFFEL & ESSER CO.
3 CYCLES X 70 DIVISIONS

K&E 10 X 10 TO THE INCH 359-5G
KEUFFEL & ESSER CO. MADE IN U.S.A.

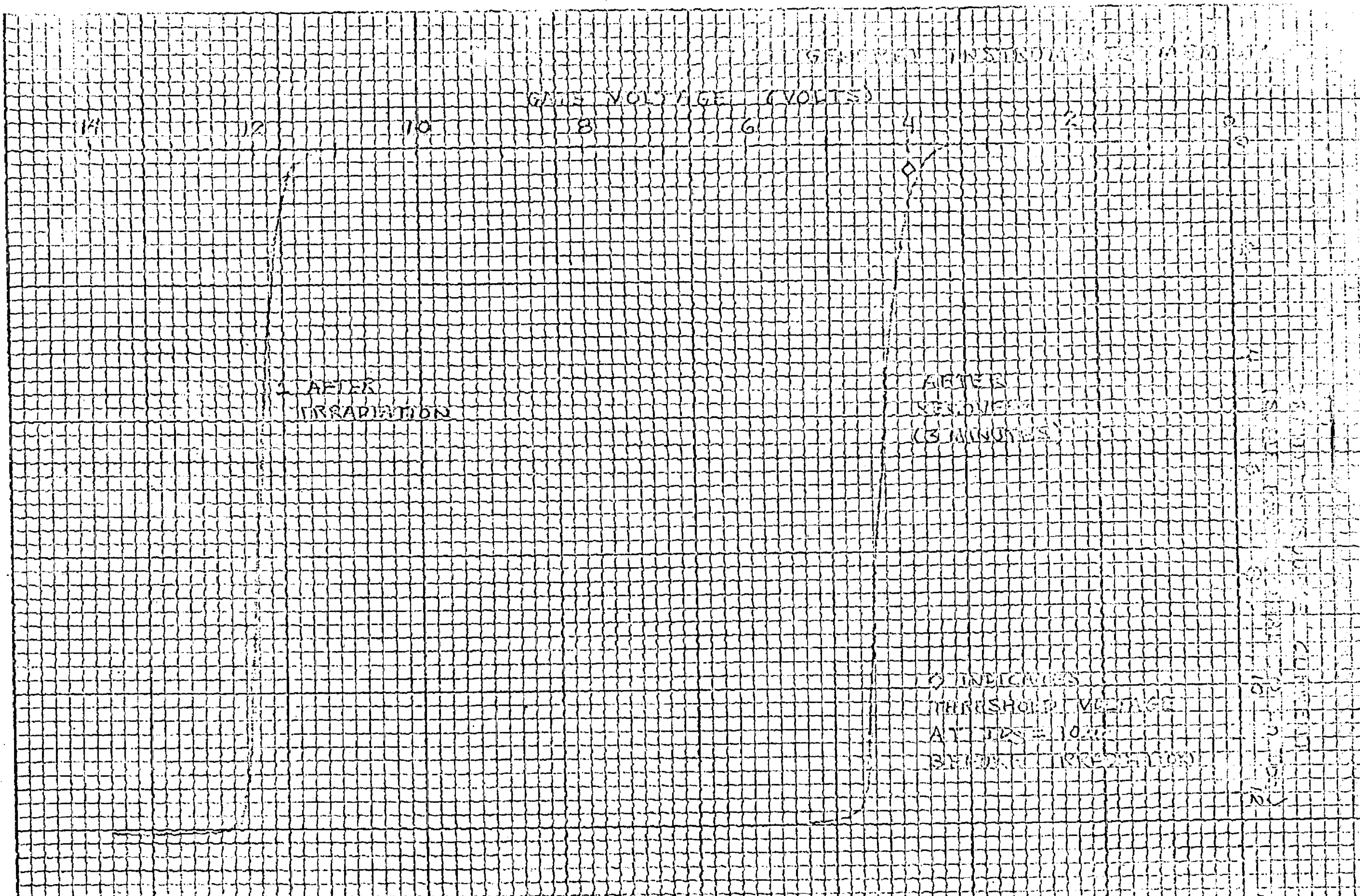


FIGURE 3 QUICK RECOVERY METHOD

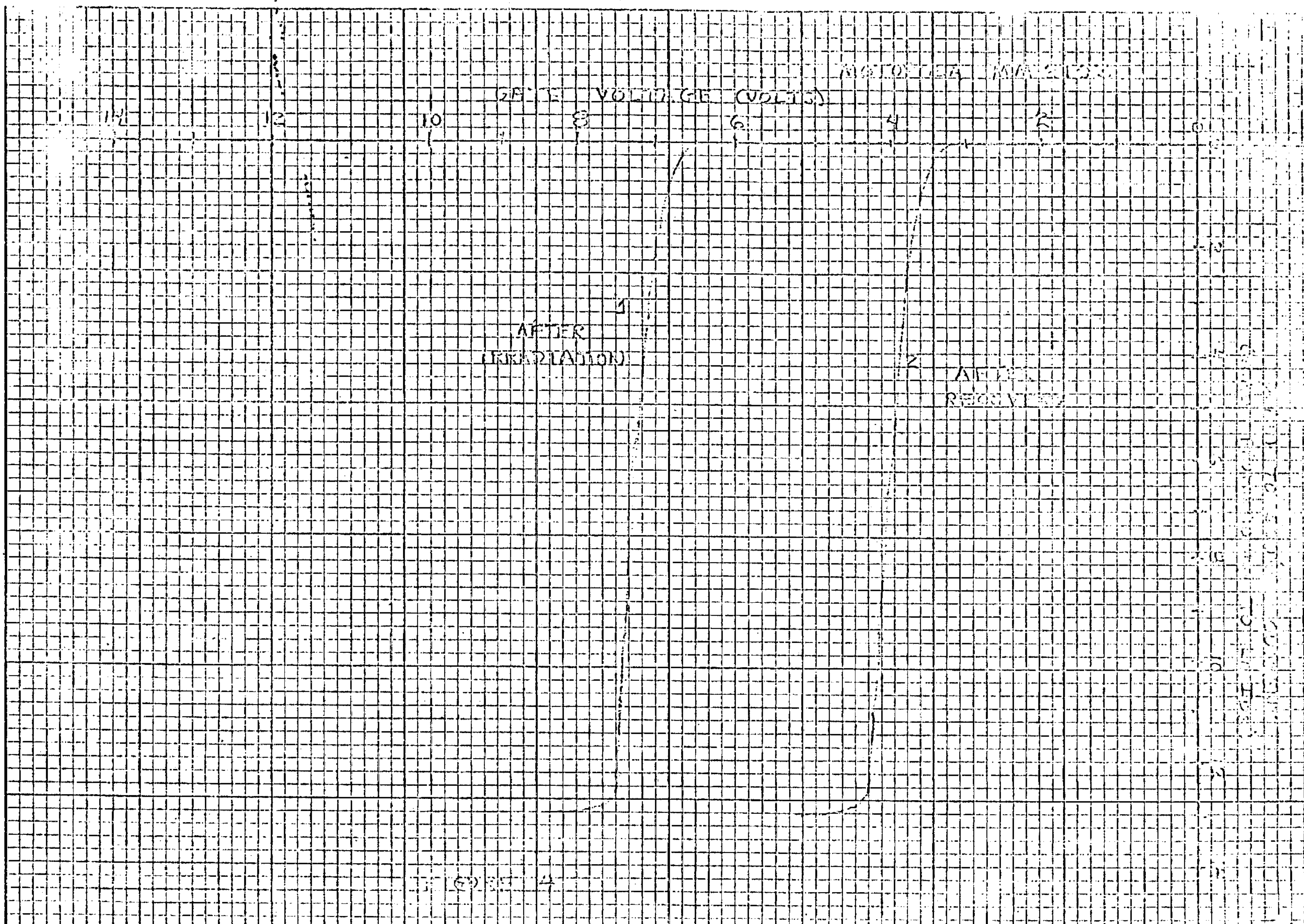


FIGURE 4